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SUBMERGED MANNED TESTING OF THE PROTOTYPE HYDROTECH AQUA HEAT SYSTEM

NAVAL SEA SYSTEMS COMMAND
Navy Experimental Diving Unit

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19. ABSTRACT
(U) Eight U.S. Navy divers were submerged in 7.2 °C (45 °F) water for a maximum of two hours in three different conditions: no heating while wearing a semidry suit, heated in a semidry suit, and heated in a 7 mm wet suit. A total of 35 W was delivered to each heating pad. Statistical analysis demonstrated that providing heating to the divers afforded no benefits in reducing the effects of cold water exposure on the skin temperature of the body extremities (fingers and toes) or in enhancing manual dexterity, grip strength, or cognitive performance when the effects of such heating were compared to those of the unheated condition. However, the participants reported that they would rather dive with the heating system than without it.

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INTRODUCTION

A cold water investigation at the Naval Medical Research Institute (NMRI) in 1996 verified the inadequacy of the diver thermal protection used by combat swimmers in long-duration, cold water missions.[1] The United States Special Operations Command (USSOCOM) has identified a need to develop a system or systems to mitigate the effects of thermal stress associated with cold water immersion during SEAL delivery vehicle (SDV) operations.[2] Active heating systems such as the resistive heating system[3] (RHS) currently authorized for Navy use (ANU) are typically complex and require a large power supply. These problems may reduce their effectiveness and reliability during cold water SDV operations when failure of either the suit or the power supply could be catastrophic. A system that reduces bulk and power requirements while providing functionally significant thermal protection may have greater utility than previously investigated systems.

Preliminary work in 1999 at the Navy Experimental Diving Unit (NEDU) identified the Hydrotech Aqua Heat System (HAHS) as one that could be worn under a wet suit, that did not restrict freedom of movement, and that appeared to improve thermal comfort.[4] SEAL Delivery Vehicle Team Two (SDVT2) has used this system on a limited basis during short-duration open water dives, and its performance during these limited dives has been favorable. This result indicates some need for a well-controlled and objective study of its performance capabilities during longer, mission-oriented SDV scenarios. An evaluation of the HAHS in a controlled environment was carried out during long-duration (6-hour) dives scheduled in June 2003 in the NEDU test pool at 7.2 °C (45 °F). This heating system was found to provide minimal improvements in diver thermal status: NEDU established that 35 W of power was being delivered to the heating pads. Thus, under NEDU guidance, Hydrotech Enterprises manufactured eight prototype heating pads capable of delivering a greater amount of heat to the diver. In August 2004 these prototype heating pads were tested in the head-out tank at NEDU, where results showed that it was not possible to safely deliver more than 35 W of power to the heating pads without increasing the risk of burning the diver. Therefore, to safely deliver additional heat to a diver, increasing the surface area of the body being heated was required.

OBJECTIVES

The objectives of this research were to:

- use the same power density (0.36 W/in^2) of the heating system that was used by SDV teams,
- increase the surface area to be heated from 192 in^2 (two heating pads) to 384 in^2 (four heating pads), and
- assess how effectively the heating system reduces the physiological and cognitive decrements associated with diving in cold water.

METHODS AND PROCEDURES

An evaluation of the effectiveness of the HAHS was conducted in the NEDU test pool, with water temperature (T_W) controlled at 7.2 ± 1.0 °C (45 ± 2.0 °F). Eight U.S. Navy divers participated in the study, with all dives being organized and supervised by a test pool diving supervisor (TPDS). NEDU personnel assisted with data collection and technical questions. Participants wore a surface-supplied United States Navy (USN) MK 20 full face mask, a Mares semidry suit or 7 mm one-piece Hyper-stretch wet suit along with a hood, booties, and gloves. All setup, maintenance, and supervisory procedures were controlled and conducted in accordance with the *U.S. Navy Diving Manual.*[5] Standard USN MK 20 communication procedures were followed during test pool dives. Backup communications included a hydrophone and hand signals.

The prototype HAHS consisted of four heating pads with a switch and power supply external to the garments. Power was surface supplied by a 12 V DC marine battery and voltage regulator. The heating pads were connected to the battery with a jacketed submersible cable and submersible plugs. The diver wore a 3 mm neoprene insulating pad between the heating pad and his skin.

Thermistors used to measure skin temperature (T_{SK}) were attached to each participant with hypoallergenic surgical tape. A thermistor was inserted 15 cm past the anal sphincter to measure rectal temperature (T_{RE}). These temperatures were monitored and recorded with Yellow Springs International (YSI) 701-Series sensors connected to a Debanes Enterprise Incorporated 1400-series thermistor transmitter connected to a National Instruments data acquisition system. Temperatures were recorded at 30-second intervals.

All eight participants dove in each of the following conditions:

- Condition 1: Mares semidry suit, heated
- Condition 2: Wet suit, heated
- Condition 3: Mares semidry suit, unheated

The schedule of dives is shown in Table 1. Divers were immersed at 10-minute intervals on each diving day.

Table 1.
Schedule of exposures for each participant.

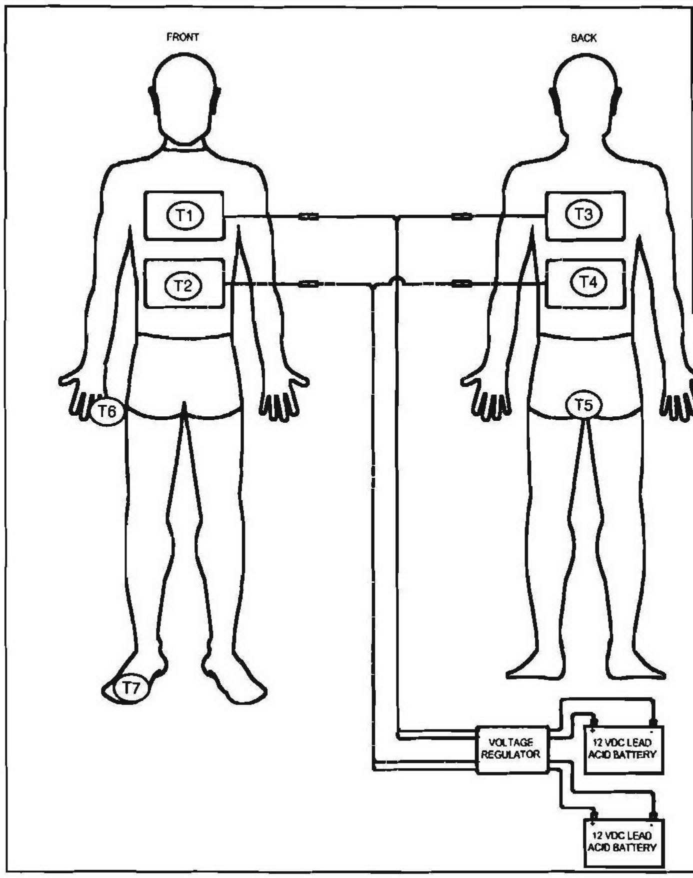
	Heated		Unheated
	Red diver	Yellow diver	Green diver
Participant	Semidry	Wet suit	Semidry
1	Day 3	Day 2	Day 8
2	Day 2	Day 8	Day 3
3	Day 8	Day 1	Day 5
4	Day 5	Day 4	Day 6
5	Day 6	Day 5	Day 4
6	Day 4	Day 6	Day 7
7	Day 1	Day 7	Day 2
8	Day 7	Day 3	Day 1

In the week before the exposure, participants completed two practice trials of each of the manual dexterity and cognitive tests. Diving was conducted on Monday, Wednesday, and Friday of each week. The following restrictions were implemented: alcohol or caffeine consumption was discouraged within 24 hours before diving; exercise was limited on dive days; normal exercise was allowed on nondive days; subjects were instructed to eat a normal, full breakfast before diving. T_{RE} and T_{SK} were monitored and recorded during diving for the duration of the exposure. A preexposure urine sample was collected from each subject, and urine specific gravity (SG_U) was measured to ensure that divers were adequately hydrated before immersion. Urine samples were collected and SG_U determined sufficiently in advance of diving in order to allow subjects adequate time to hydrate if it was found that they were dehydrated.

The experiment was conducted in three phases: Preexposure, Exposure, and Postexposure.

1. PREEXPOSURE PHASE

Predive weights were recorded, and urine samples were collected to assess hydration status by measuring SG_U. A predive hydration schedule consisted of at least two L of fluid in the four hours before diving. Once the predive weight had been recorded, fluid intake was not restricted. A T_{RE} sensor was inserted and checked to verify that the sensor was working properly before the participant donned the dive gear. Each diver was instrumented with T_{SK} sensors at six different sites, in addition to the T_{RE} sensor (Figure 1).



T1	Center of right pectoralis
T2	Center of right rectus abdominis
T3	Trapezium, medial to scapula
T4	Center of thoracolumbar fascia
T5	Rectal
T6	Lateral tip of right little finger
T7	Lateral tip of right little toe

Figure 1. Temperature sensor placement.

Following instrumentation checks, participants donned four heating pads (Figures 2 and 3) in the heated conditions: two on the front (chest and abdomen), and two on the back (upper and lower). They then donned immersion gear, either the Mares semidry suit (Figure 4) or the wet suit.

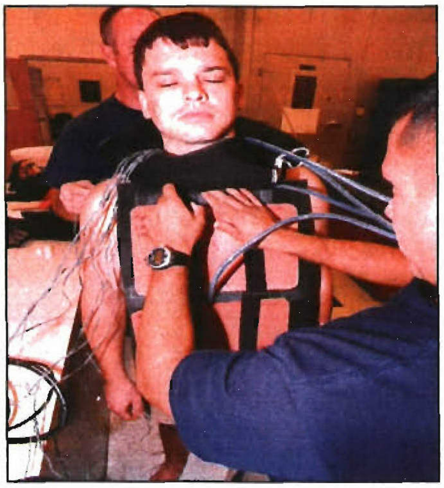


Figure 2. Heating pads donned on chest and abdomen.

Figure 3. Heating pads donned on upper and lower back.

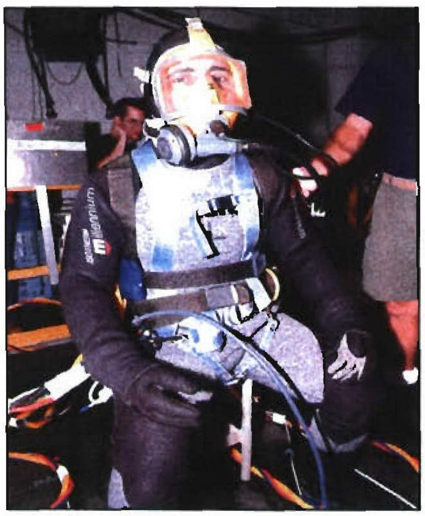


Figure 4. The Mares semidry suit.

A neoprene pad three millimeters thick was placed between the heating pads and the skin of the diver. In Condition 3 (unheated), the participants wore no heating pads at all. Under the direction of the TPDS, the three subjects on each dive entered the NEDU test pool at 10-minute intervals.

2. EXPOSURE PHASE

After the subjects had descended to the bottom of the NEDU test pool, they picked up an 8-pound SmartBell® from the pool bottom and slowly rotated their arms in a clockwise direction, making 10 circle motions from their ankles to above their heads.

They also completed the same motion 10 times in the counterclockwise direction, to ensure that their dress was flooded with water before the testing began. The heating pads were energized after the participants had been submerged for 10 minutes and after their dress had been flooded. Following this warm-up exercise, participants completed a series of hand dexterity and cognitive tests, each of which is explained in detail below.

Turning Test (TT): The turning test is from a larger battery of manual dexterity tests called the Minnesota Manual Dexterity Test.[6,7] The purpose of this TT is to measure simple but rapid eye-hand-finger movements. For underwater testing purposes, a submersible version of the hardware was constructed. The only change from the dimensions of the standard Minnesota Manual Dexterity Test was in the height of the counters, which were increased from one-half to one inch so that they could be picked up while subjects were wearing gloves (Figure 5).

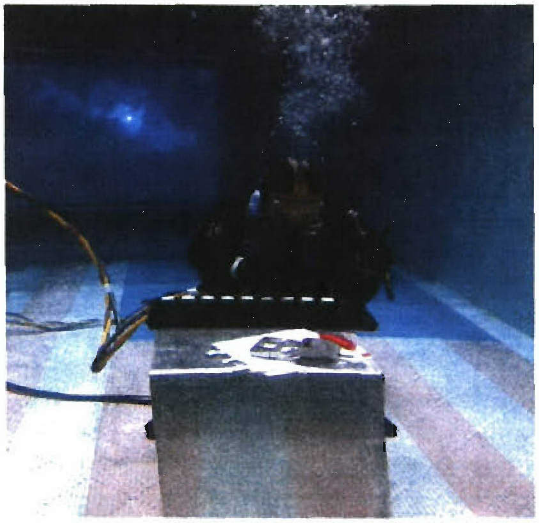


Figure 5. Participant completing the turning test.

With the *left* hand, the participant was required to pick up the disk from the upper right corner, turn the disk while passing it to his *right* hand, and return it to the hole with the bottom side facing *up*. Then he worked from the *left* across the board on the top row. On the second row he did the reverse: he picked up the disk with his *right* hand, turned it, and then replaced it with his *left* hand (Figure 6). This sequence was completed twice. The measure of performance was the time, in seconds, that it took to complete both trials.

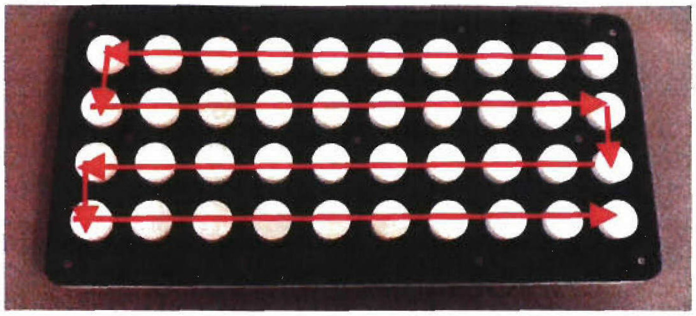


Figure 6. Turning test sequence.

Maximal handgrip strength (HG): Maximal handgrip strength was measured with a hand dynomometer. Each subject performed three maximal voluntary contractions (MVCs) with his dominant hand, and the average of these three was recorded. Because the participant was wearing gloves, the added bulk of the neoprene did not allow all fingers to fit into the head of the dynomometer grip. Therefore, the participant's little finger rested outside the grip head. The measure of performance was the mean grip strength (kg) of all three MVCs for each hand.

Trail Making Test—Part A and Part B (TMT): The Trail Making Test, taken from the Halstead-Reitan Neuropsychological Test Battery,[8] is a standardized paper-and-pencil measure used to assess visual path-finding and path-following tasks. The test consists of two parts (A and B), each of which requires the participant to connect 25 encircled dots by making pencil lines in the appropriate order. Part A required the subject to draw lines through the numerical circles in order (i.e., 1 to 2, 2 to 3, . . . through 25). Part B required him to draw lines through numerical and alphabetical circles in alternating order (i.e., 1 to A, A to 2, 2 to B, . . . and through L to 13). Any error in sequencing had to be corrected by the participant immediately. The measure of performance to complete each of the two trials was time in seconds.

Digit span (DS): The two-part digit span test was presented to assess attention, concentration, vigilance for auditory stimuli, and short-term memory.[9] In the first part, a series of numbers from three to eight digits in length was read to the participant. After the number series had been read, the participant was then instructed to repeat the numbers out loud in the same order in which they had been presented to him. In the second part, a separate series of numbers ranging from two to eight digits long was read to the participant. After the number series had been read, the participant was instructed to repeat the numbers aloud in the *reverse* order in which they had been presented to him. In addition to attention, concentration, vigilance for auditory stimuli, and short-term memory, this task required a degree of mental manipulation and flexibility.[9] One point was awarded each time a series of digits was repeated correctly (Appendix A); this point system was used for both parts of the test. Once a participant was incorrect on two consecutive trials of a given digit series, the test was terminated. The maximum possible score was 12 under each of the two parts.

Following completion of the hand dexterity and cognitive tests, participants sat idle and watched a movie with their backs against the wall at the bottom of the test pool. At 15-

minute intervals during this time they were asked a series of questions (Appendix B) related to their thermal status. Answers to these questions provided investigators with information to help monitor participants and assess risk for them. If subjects were more than 80% certain that they would be unable to continue for another 15 minutes or if only 10 minutes of the two-hour maximum exposure remained, they then undertook the same series of hand dexterity and cognitive tests that they had completed at the beginning of the exposure.

Any immersion was terminated when one of the following criteria was met:

- the subject requested it for any reason;
- a T_{RE} reached 35.0 °C (95.0 °F) at any time;
- a T_{RE} reached ≤35.5 °C (95.9 °F) continuously for five minutes;
- a T_{SK} reached ≥40.8 °C (105.5 °F) at any time;
- the dive watch supervisor (DWS) directed — or the principal investigator (PI), medical deck supervisor (MDS), dive watch medical officer (DWMO), or diving corpsman deemed it unsafe to continue; or
- a medical emergency was declared by the DWMO.

3. POSTEXPOSURE

Once the Exposure Phase of the study was complete, the subjects exited the water under the supervision of the TPDS; were stripped of all dive gear, skin sensors, and thermistors; were escorted directly to a heated bath; and were asked to complete the Postexposure Questionnaire (Annex C).

RESULTS

RESULTS: PHYSIOLOGICAL DATA

Figures 7 through 10 show that T_{SK} under each of the heating pads in the heated conditions eventually recovered to a level equal to or greater than baseline temperatures. Furthermore, and certainly not unexpectedly, the temperatures of the skin under the heating pads were higher in the heated conditions than in the unheated condition.

It was necessary for three participants in the heated wetsuit condition, and one participant in the heated semidry suit condition, to deliberately allow cold water to egress into their suits to prevent their upper back T_{SK} from rising above 40.8 °C (105.5 °F).

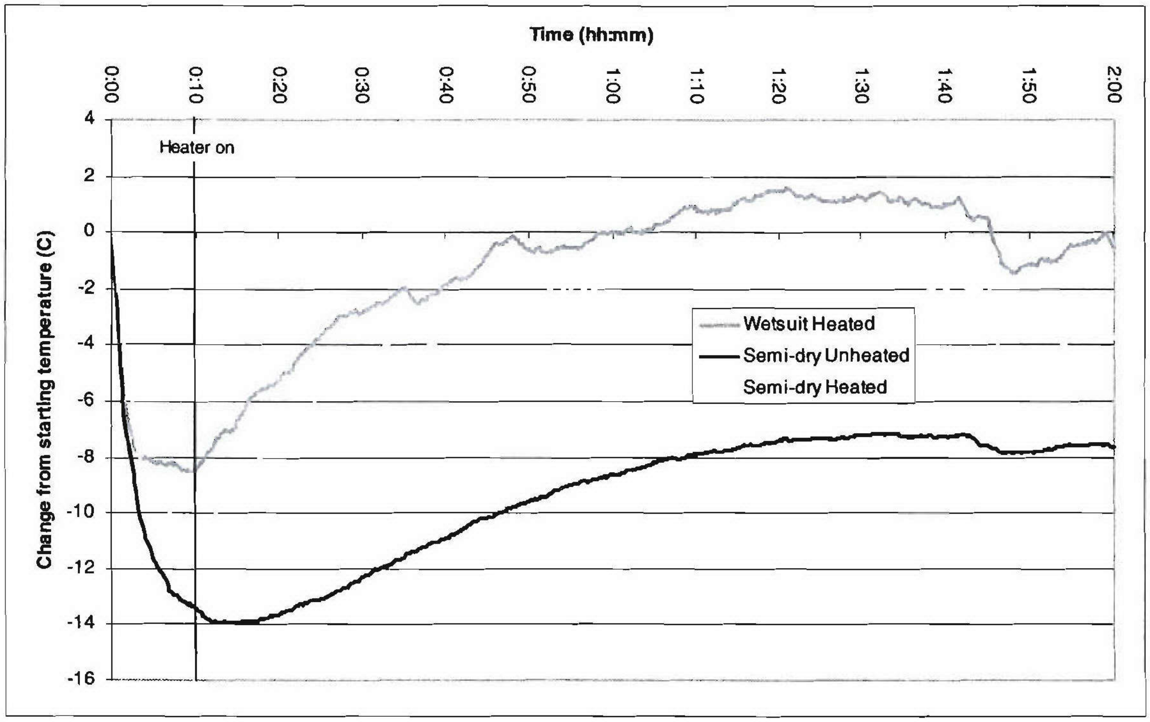


Figure 7. Change in chest temperature from baseline, as measured by sensor T1.

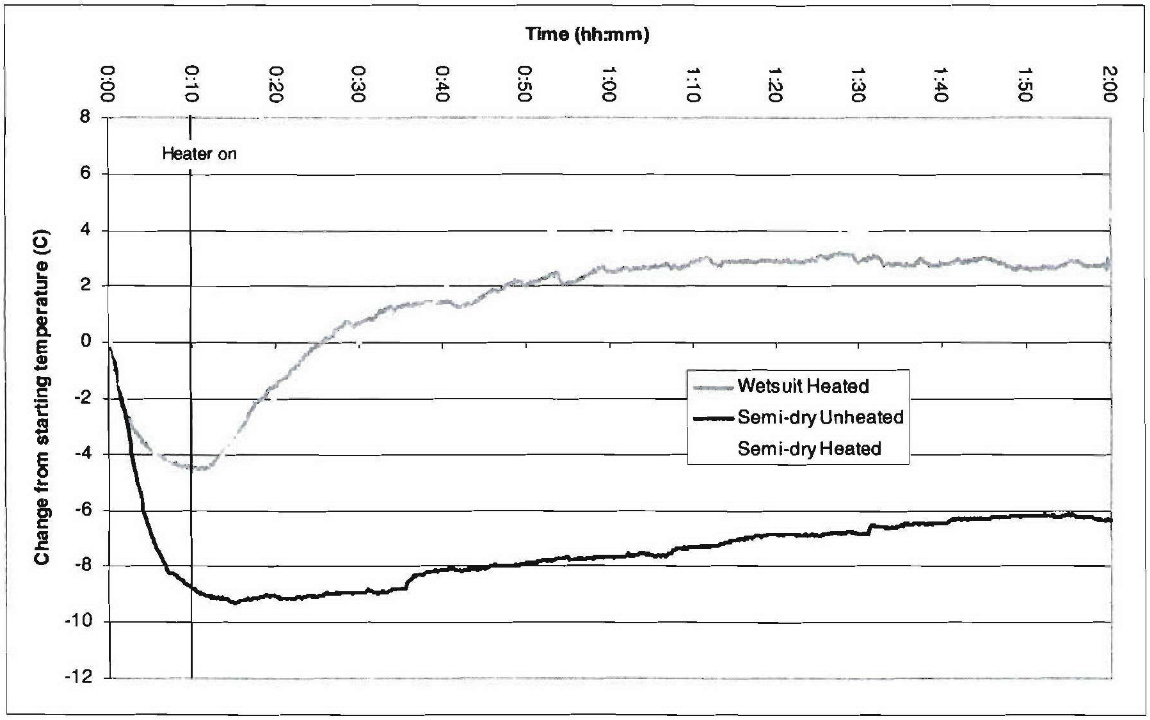


Figure 8. Change in abdomen temperature from baseline, as measured by sensor T2.

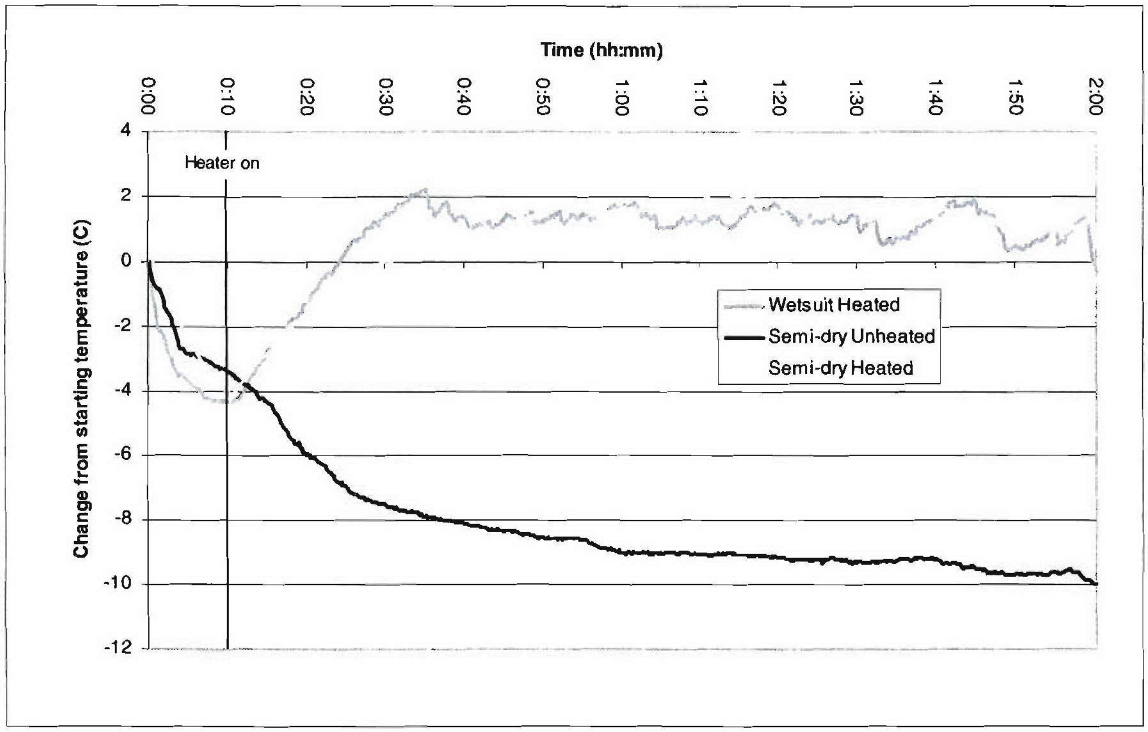


Figure 9. Change in upper back temperature from baseline, as measured by sensor T3.

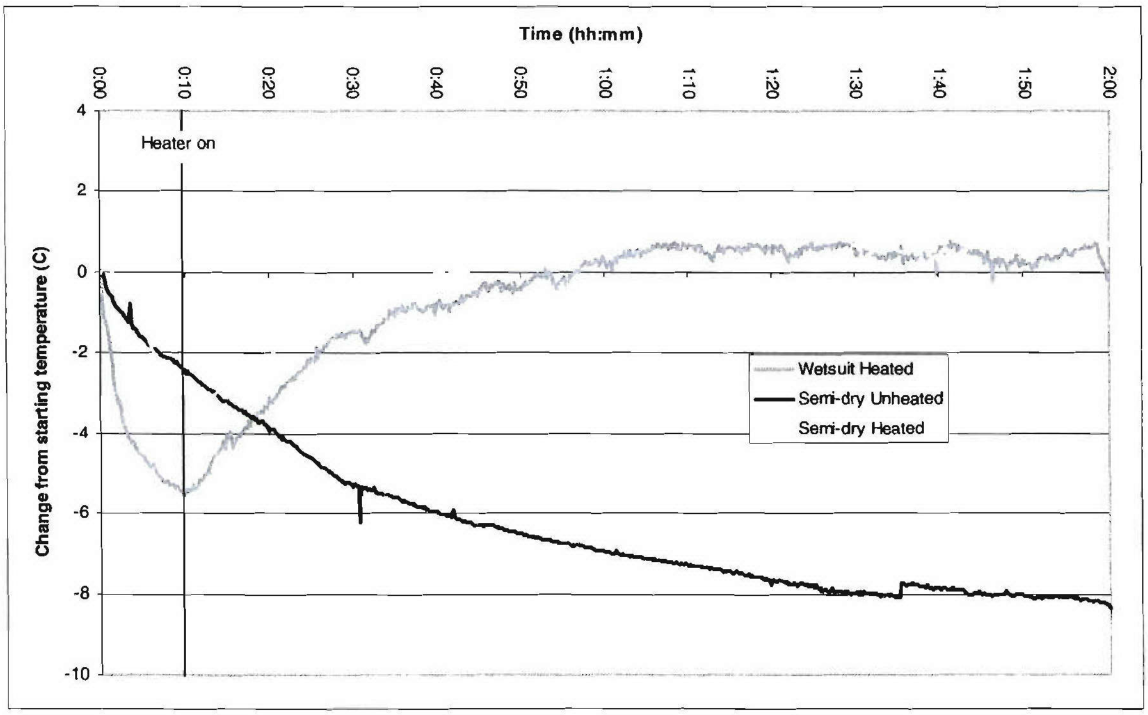


Figure 10. Change in lower back temperature from baseline, as measured by sensor T4.

Figure 11 shows that the T_{RE} of the participants decreased in all three conditions during the exposure. However, the T_{RE} differences between the conditions were not found to be significant.

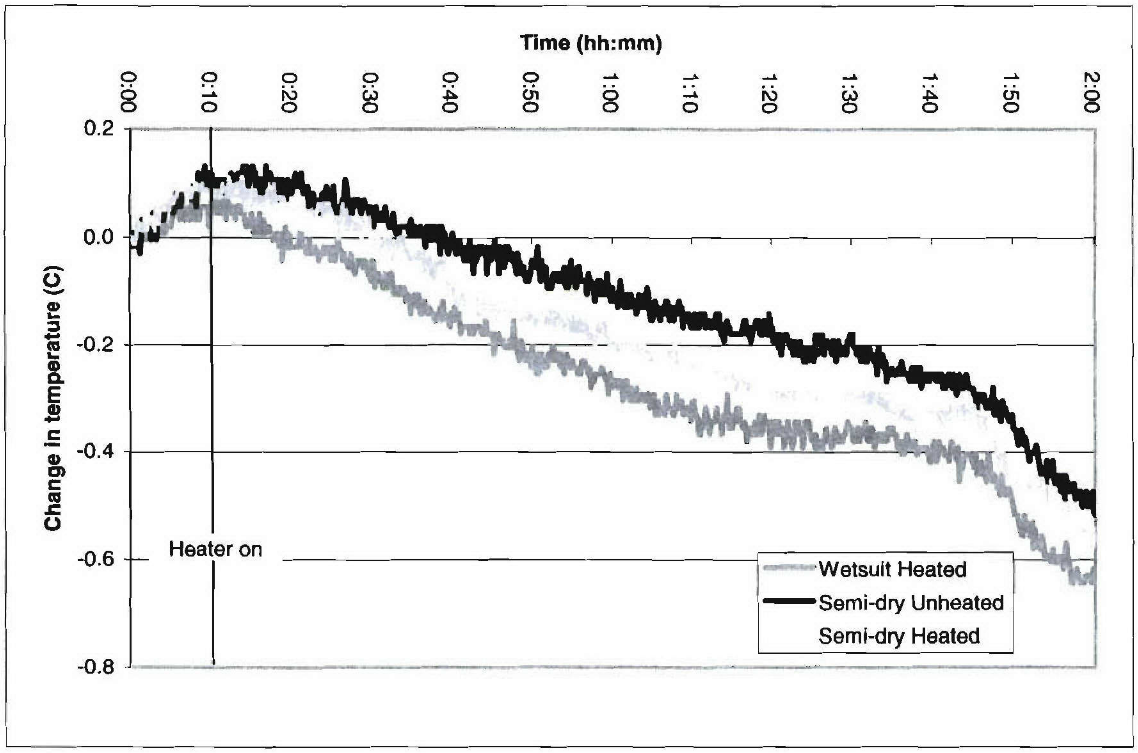


Figure 11. Change in rectal temperature from baseline, as measured by sensor T5.

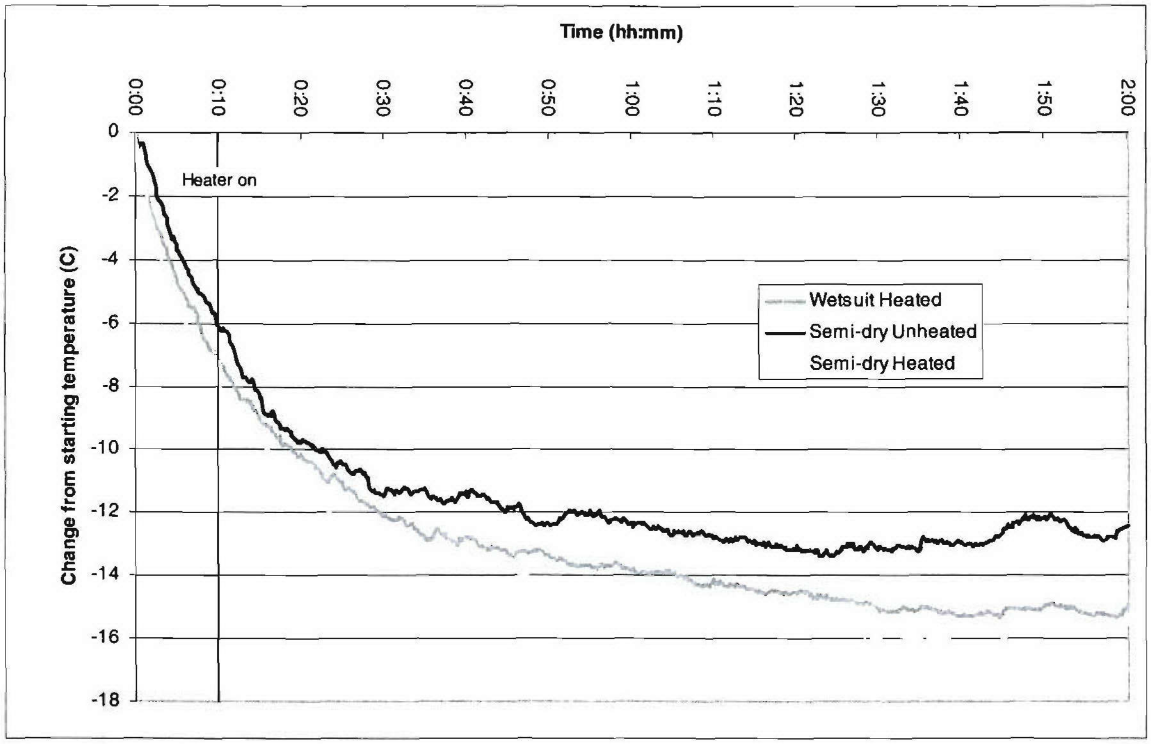


Figure 12. Change in finger temperature from baseline, as measured by sensor T6.

Figures 12 and 13 show that finger and toe temperatures decreased throughout the exposure in all three conditions. However, the temperature change appears to be leveling off toward the end of the exposure. Differences between the temperature drops over time for toes and fingertips in the semidry suit conditions were analyzed by nonlinear regression and the F test.

Statistically, there were counterintuitive differences between the two conditions (that is, the participants' toes and fingers were warmer in the unheated condition), but those differences were also present during the 10 min control period: they were thus attributed to artifact. The reason for this anomalous result is not known.

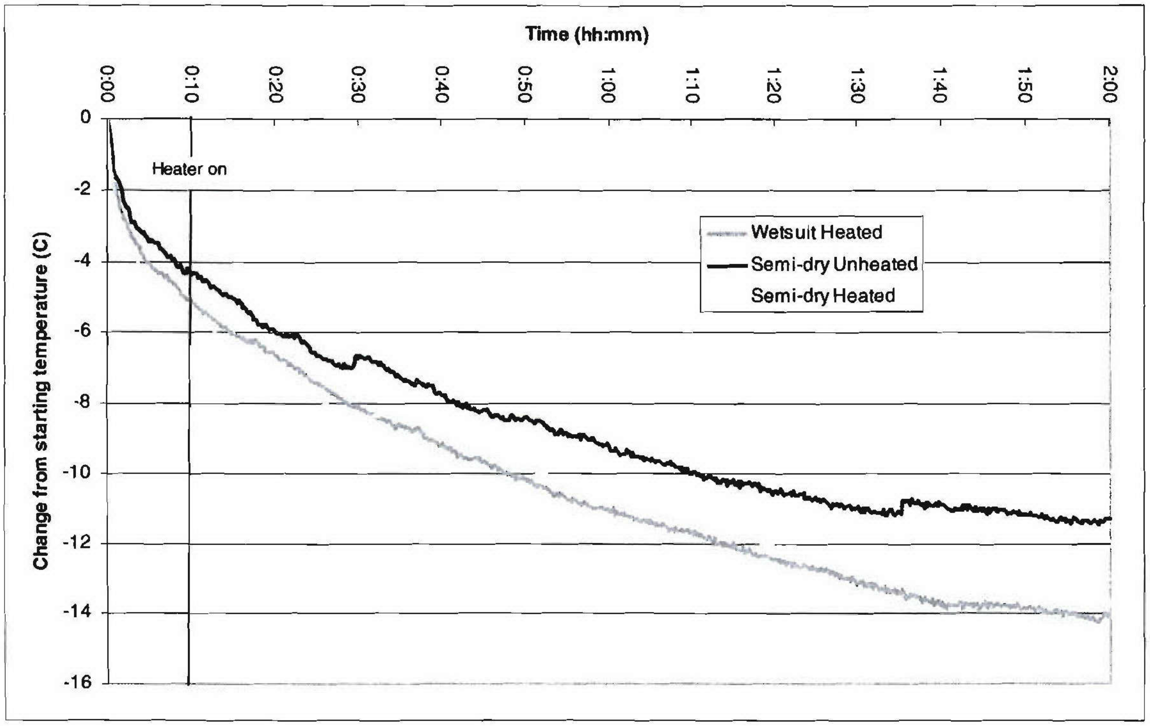


Figure 13. Change in toe temperature from baseline, as measured by sensor T7.

RESULTS: COGNITIVE AND HAND DEXTERITY TESTS

To assess whether there was a significant learning effect, a one-way repeated analysis of variance (ANOVA) was carried out to compare test scores at the beginning of the first, second, and third exposures of each participant (regardless of the condition).

Table 2.
Comparison of performance of cognitive and manual dexterity tests at the beginning of the exposure.

Test	Exposure 1		Exposure 2		Exposure 3		F value*	% increase exp 1 to exp 3
	mean	sd	mean	sd	mean	sd		
Turning (sec)	**170.4**	46.2	**165.1**	60.6	**137.4**	29.8	2.9	19
Dominant grip strength (kg)	**32.2**	4.3	**30.2**	6.5	**32.0**	4.6	1.3	1
Nondominant grip strength (kg)	**32.5**	5.2	**31.9**	7.2	**31.8**	5.5	0.2	2
Trails A (sec)	**30.4**	7.9	**24.4**	6.9	**24.0**	7.0	2.5	21
Trails B (sec)	**55.9**	18.5	**46.0**	17.7	**48.3**	21.7	0.8	14
Forward digit span (#)	**7.6**	2.6	**7.9**	3.0	**8.6**	2.0	0.9	12
Backward digit span (#)	**6.1**	2.7	**7.1**	1.8	**6.8**	2.1	0.9	10

* degrees of freedom (2, 14)

The turning test and trails A were the only tests approaching significance. However, learning appears to have occurred in all of the tests except that for hand grip.

To quantify the effects of the exposure on the performance of the cognitive and hand dexterity tests and to compare the effects of the different types of dress, two-way repeated measures ANOVAs with time (beginning versus end of exposure) and condition (unheated semidry suit, heated wet suit, and heated semidry suit) were completed.

Turning test. Participants took a significantly longer time to complete the turning test at the end of the dive than at the beginning ($F(1,7) = 6.1$, $p < .05$; see Table 2 and Figure 14). No significant main effect of dress ($F(2,14) = 1.7$, n.s.) or significant interaction between dress and time ($F(2,14) = 0.5$, n.s.) was found.

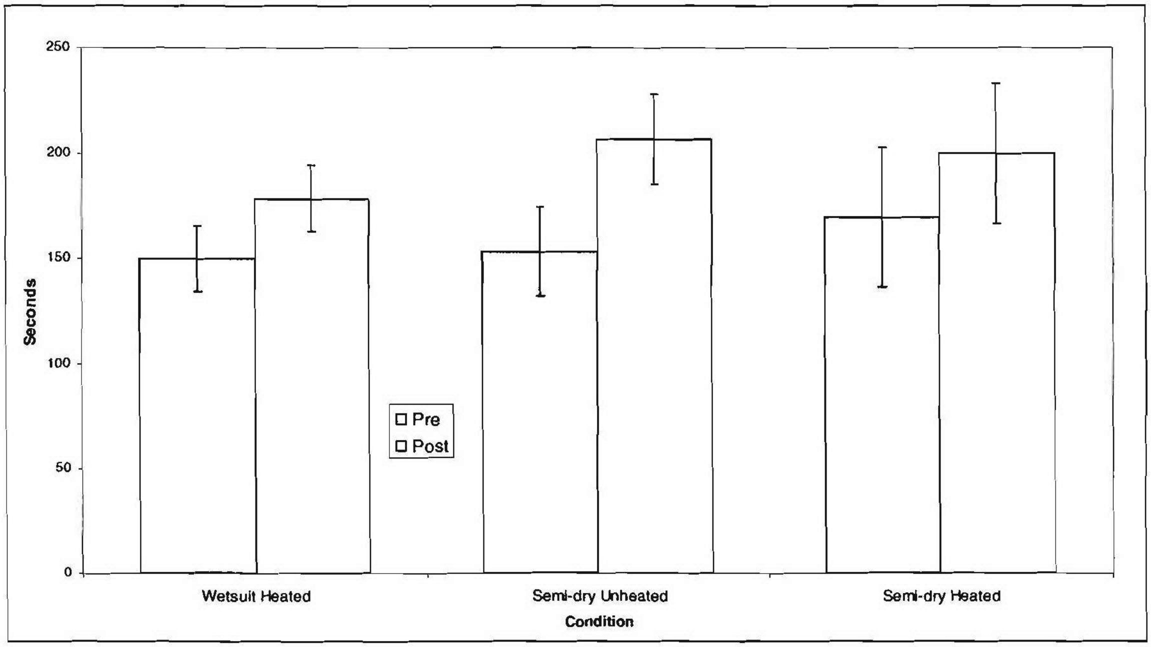


Figure 14. Mean time to complete the turning test (error bars represent a 95% confidence interval).

Dominant hand grip strength. The dominant hand grip strength of participants was significantly lower at the end of the dive than at the beginning ($F(1,7) = 27.4$, $p < .05$; see Table 2 and Figure 15). No significant main effect of dress ($F(2,14) = 2.1$, n.s.) or significant interaction between condition and time ($F(2,14) = 1.7$, n.s.) was found.

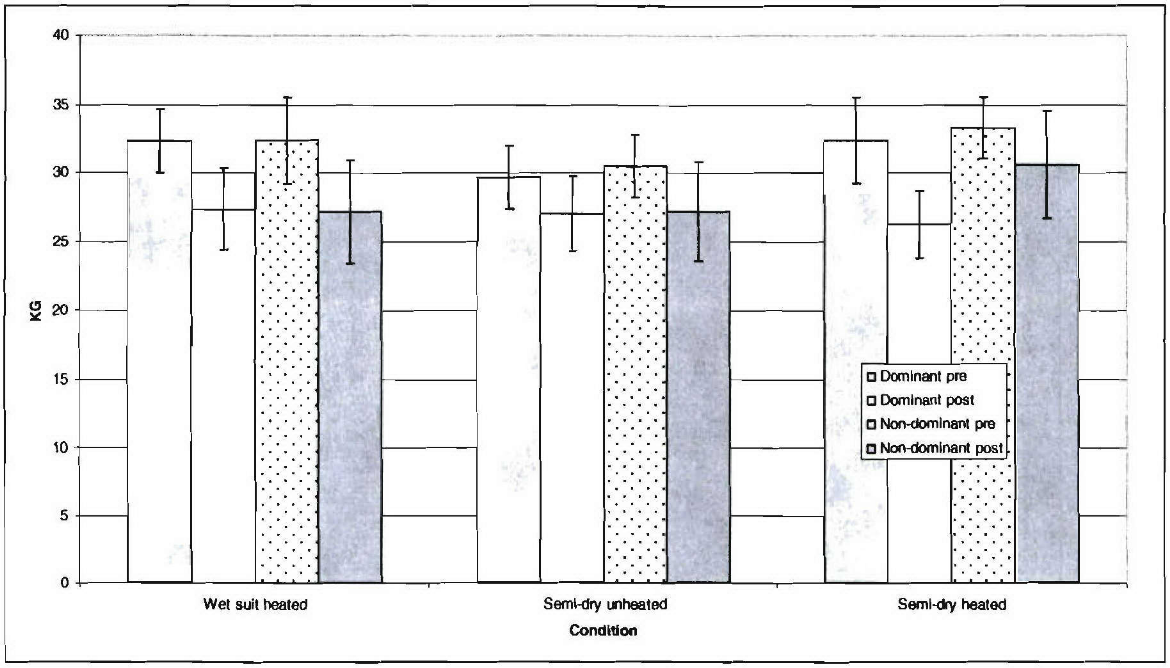


Figure 15. Mean grip strength (error bars represent a 95% confidence interval).

Nondominant hand grip strength. The nondominant hand grip strength of participants was significantly lower at the end of the dive than the beginning ($F(1,7) = 15.8$, $p < .05$; see Table 2 and Figure 15). No significant main effect of dress ($F(2,14) = 2.5$, n.s.) or significant interaction between condition and time ($F(2,14) = 0.39$, n.s.) was found.

Trails A. No significant main effects of time ($F(1,6) = 0.55$, n.s; see Table 2 and Figure 16) or dress ($F(2,12) = 0.22$, n.s.) nor any significant interaction effects ($F(2,12) = 0.45$, n.s.) were found.

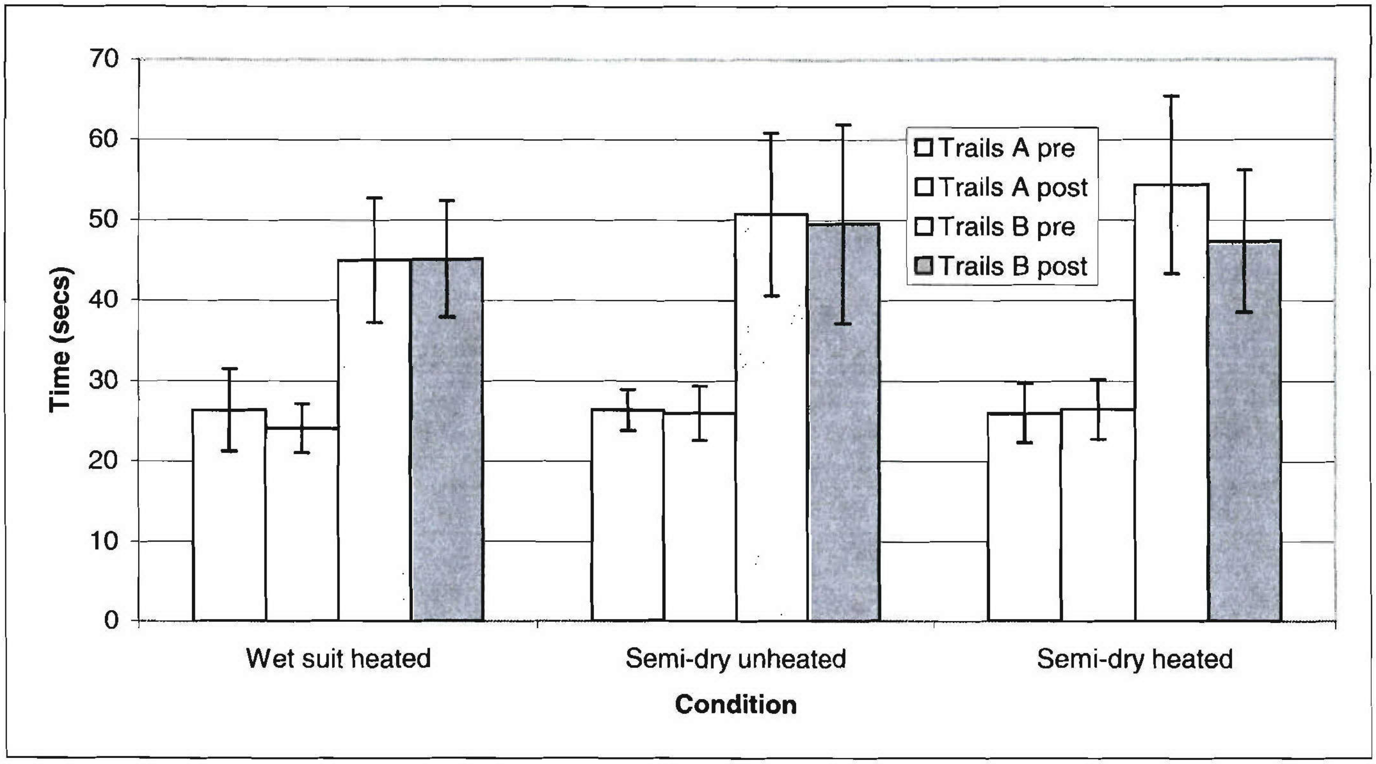


Figure 16. Mean completion time for the Trails tests (error bars represent a 95% confidence interval).

Trails B. No significant main effects of time (F(1,7) = 0.52, n.s.; see Table 2 and Figure 16) or dress (F(2,14) = 0.67, n.s.) nor any significant interaction effects (F(2,14) = 0.42, n.s.) were found.

Forward digit span. No significant main effects of time (F(1,7) = 0.45, n.s.; see Table 2 and Figure 17) or dress (F(2,14) = 1.44, n.s.) nor any significant interaction effects (F(2,14) = 0.77, n.s.) were found.

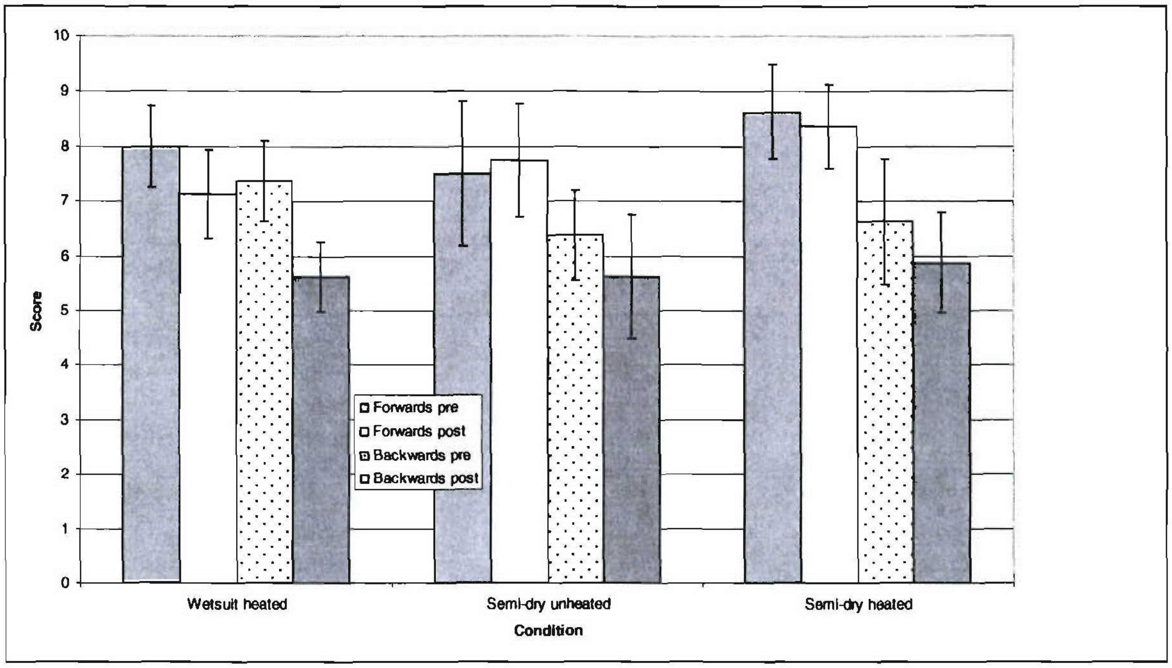


Figure 17. Mean digit span scores (error bars represent a 95% confidence interval).

Reverse digit span. The reverse digit span of participants was significantly longer at the beginning of the dive than at the end ($F(1,7) = 6.24$, $p < .05$; see Table 2 and Figure 17). No significant main effect of dress ($F(2,14) = 0.46$, n.s.) or any significant interaction between dress and time ($F(2,14) = 0.90$, n.s.) was found.

RESULTS: SUBJECTIVE DISCOMFORT

Table 3 shows that following the unheated exposure, participants were more likely to report being uncomfortable than after the heated exposures and that the exposure would detrimentally affect their performance.

Table 3.
Levels of comfort reported by participants during each exposure.

Total = 8 participants	Wet suit heated	Semidry unheated	Semidry heated
Comfort during the exposure*	1	5	2
If heated, effectiveness of system#	6	-	5
Effect of exposure on physical performance#	2	6	1
Effect of exposure on mental performance#	0	2	0

* number of participants rating the statement poor/very poor
\# number of participants rating the statement big/very big effect

Table 4 documents the numbers of participants who complained of cold hands, feet, and other body parts. The mean level of intensity of the cold — a range from 1 (mild) to 5 (severe) — is also given. Other areas of discomfort included arms, legs, and head.

Table 4.
Levels of cold intensity reported by participants.

Total = 8 participants	Hands		Feet		Other	
	Freq	Intensity	Freq	Intensity	Freq	Intensity
Wet suit heated	8	3.4	7	3.3	6	2.2
Semidry unheated	7	3.9	7	3.4	2	3.5
Semidry heated	7	3.4	6	3.5	0	-

DISCUSSION

DISCUSSION: PHYSIOLOGICAL DATA

The physiological data seem to suggest that in the unheated condition the fingers and toes of participants did not cool as quickly as in the heated condition. However, the smaller decrease in finger and toe temperatures in the unheated than in the heated condition was also present during the first ten minutes of the experiment, when no heat was provided to the participants in all conditions. So the mean temperature drop would be expected to be the same in all conditions.

Three explanations might be given for this unexpected phenomenon: behavioral differences, calibration error, or psychophysiological responses.

With the knowledge that they were going into cold water without the benefit of a heating source, the participants might have taken additional care when dressing for the exposure, to ensure that they conserved as much heat as possible. Or when they were in the water, the participants may also have behaved differently (e.g., pulling their fingers out of the gloves) in the unheated condition than they did in the heated condition.

Secondly, although the sensors were calibrated each day and temperature changes rather than absolute temperature readings were examined, it is impossible to completely discount the possibility of sensor error. However, sensor error would require the same error to have occurred in the finger, toe, and T_{RE} sensors.

Thirdly, some kind of psychophysiological response may have occurred in which the participants knew that they were going to be entering cold water without any heating and so their bodies reacted to this knowledge by increasing the temperatures of their extremities.

Neverthless, despite these possible explanations, it can still be determined that the heating pads are unable to provide sufficient heat to the body to sufficiently vasodilate the extremities to keep them warm. Brajkovic and Ducharme[9] have demonstrated that heating the core can maintain hand temperature at 35.3 °C (95.5 °F; and retain manual

dexterity). In this experiment carried out in -25 °C (-13 °F) air, heating the core with a power of 111 W was required to keep the skin under the heated vest at 42 °C (107.6 °F). Furthermore, as described in the next section, no differences in hand dexterity or grip strength resulted, despite the differences in finger T_{SK} between the heated and unheated conditions.

DISCUSSION: HAND DEXTERITY AND COGNITIVE TESTS

Although none of the learning effects was found to be significant at the 5% level, this does not mean that learning has not occurred. The lack of significance is due in part to the small sample size. Table 2 indicates that substantial improvements occurred from Exposure One to Exposure Three in all the tests except that for grip strength. If we assume that an exposure will detrimentally affect performance, then a learning effect will result in underestimating the effect of the exposure. Thus, if a significant difference is evident between the performance of the tests at the beginning and the end of an exposure, then the beneficial effect of learning is not as strong as the detrimental effect of the exposure.

The effect of learning on the comparisons of performance in the three different conditions was accounted for by balancing the order in which those different conditions were completed: every participant did not complete the same condition first. It would have been preferable to carry out work-up dives in an ambient water temperature until the participants' performance on the tests had reached a plateau. However, the time, resources, and personnel were not available to complete such extensive work-ups.

Hand dexterity and grip strength. Comparing task performance at the beginning and end of the exposures showed significant losses in hand dexterity and hand strength, as measured by the turning test and the dynamometer, respectively. This finding is consistent with other cold exposure studies.[10,11] Local cooling (i.e., that in which the body remains warm while the hands and forearms are cooled) has been found to produce significant impairments of manual dexterity[10] and grip strength.[11] Furthermore, cooling the body has been found not to affect manual performance as long as the hands remain warm. Gaydos[12] cooled the body of participants to a mean T_{SK} of 25.6 °C (78.1 °F) and found no decrement in manual dexterity with hand T_{SK} maintained at 26.7 °C (80.1 °F) or higher. Thus, local hand temperature is the main factor influencing manual dexterity. Therefore, it is not surprising that heating provided to the participant's torso does not beneficially affect manual dexterity or grip strength, as shown by a lack of significant differences between the heated and unheated conditions evaluated in the current study.

Trails A and B. No significant differences were found for the Trails A or B tasks, although a learning effect may possibly have been greater than the detrimental effect of the exposure. However, other researchers have concluded that cold affects tasks that are complex or perceptually demanding and require concentration or short-term memory.[13,14] Thus, the Trails tests may not be sufficiently complex to be affected by the exposure.

Digit span. As with performance on the Trails tests, no significant effect of time or condition was evident on the forward digit span test, but there was a significant effect of time on the backward digit span test. Similar findings have been reported in the research literature. Giesbrecht et al[13] immersed six participants without insulation in 8 °C (46.4 °F) water for 55 to 80 minutes and found no effect of the exposure on forward digit span, but a significant detrimental effect for the backward digit span task. Davis et al[14] immersed 16 divers (dressed in 5 mm wet suits) in 5 °C (41 °F) water for 35 to 50 minutes and found no effect of the exposure on forward digit span performance. Therefore, as with the Trails tests, the forward digit span may not have been cognitively demanding enough to have been affected by the cold exposure.

DISCUSSION: SUBJECTIVE DISCOMFORT

In the unheated condition a greater number of participants reported feeling increasingly uncomfortable and thought that the exposure would have a big or very big effect on their physical and mental performance than in the heated conditions. Thus, despite no evidence of performance differences in the manual dexterity and cognitive tests, the participants perceived that the heating system was beneficial in terms of comfort and performance.

However, when participants were asked to report what areas of the body felt cold during the exposures, hands and feet were the most commonly identified body areas. When asked to describe the intensity of the discomfort, participants gave a mean response that was between moderate and severe. Overall, participants perceived their intensity of discomfort to be most uncomfortable in the heated wet suit; being unheated in the semidry suit was less uncomfortable. Thus, despite reporting that the heated conditions were more comfortable than the unheated, participants describing the intensity of their discomfort in particular body parts indicated that being heated in the wet suit seemed to be the most uncomfortable.

Other researchers have concluded that humans are unable to reliably assess how cold they are.[15] Therefore, cold sensation does not appear to be a useful metric in determining how cold the body actually is, and other indices such as exposure time and water temperature are more reliable.

CONCLUSIONS

From a physiological perspective, the heating pads do not appear to reduce the participant's temperature decrease resulting from cold water exposure. The use of the heating pads did not significantly affect manual dexterity or grip strength. The only method for retaining these abilities is to apply heating directly to the hands and forearms. Furthermore, using the heating pads did not affect cognitive performance as measured by the tests in this experiment.

However, although no physiological or cognitive evidence supports the use of the heating pads, the participants preferred to have these pads when they were diving in the experiment. This finding should not be underestimated.

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APPENDIX A

1. Turning test

Time 1	Time 2

2. Grip Strength

RIGHT HAND	Left hand
1.	
2.	
3.	

3. Trails A	4. Trails B
Time	Time

5. & 6. Digit span

		Forwards				Backwards	
1	Trial 1	6-4-3-9		1	Trial 1	6-2-9	
	Trial 2	7-2-8-6			Trial 2	4-1-5	
2	Trial 1	4-2-7-3-1		2	Trial 1	3-2-7-9	
	Trial 2	7-5-8-3-6			Trial 2	4-9-6-8	
3	Trial 1	6-1-9-4-7-3		3	Trial 1	1-5-2-8-6	
	Trial 2	3-9-2-4-8-7			Trial 2	6-1-8-4-3	
4	Trial 1	5-9-1-7-4-2-8		4	Trial 1	5-3-9-4-1-8	
	Trial 2	4-1-7-9-3-8-6			Trial 2	7-2-4-8-5-6	
5	Trial 1	5-8-1-9-2-6-4-7		5	Trial 1	8-1-2-9-3-6-5	
	Trial 2	3-8-2-9-5-1-7-4			Trial 2	4-7-3-9-1-2-8	
6	Trial 1	2-7-5-8-6-2-5-8-4		6	Trial 1	9-4-3-7-6-2-5-8	
	Trial 2	7-1-3-9-4-2-5-6-8			Trial 2	7-2-8-1-9-6-5-3	
		Total				Total	

ANNEX B

SUBJECTIVE RATING SCALE

How are you feeling at this moment?

Time	Normal										Quit
15 minutes	0	1	2	3	4	5	6	7	8	9	10
30 minutes	0	1	2	3	4	5	6	7	8	9	10
45 minutes	0	1	2	3	4	5	6	7	8	9	10
60 minutes	0	1	2	3	4	5	6	7	8	9	10
75 minutes	0	1	2	3	4	5	6	7	8	9	10
90 minutes	0	1	2	3	4	5	6	7	8	9	10
105 minutes	0	1	2	3	4	5	6	7	8	9	10

What is the likelihood that you will not last the next 15 minutes?

Time	0%										100%
15 minutes	0	10	20	30	40	50	60	70	80	90	100
30 minutes	0	10	20	30	40	50	60	70	80	90	100
45 minutes	0	10	20	30	40	50	60	70	80	90	100
60 minutes	0	10	20	30	40	50	60	70	80	90	100
75 minutes	0	10	20	30	40	50	60	70	80	90	100
90 minutes	0	10	20	30	40	50	60	70	80	90	100
105 minutes	0	10	20	30	40	50	60	70	80	90	100

ANNEX C

POSTEXPOSURE QUESTIONNAIRE

Name of diver: ______________________ Date of dive: ____________________

Condition: Heated Unheated

Dive dress: Mares semidry Wetsuit

Please rate each statement on the five-point scale below by circling the corresponding number, and provide any additional written comments.

	Very poor	Poor	Neither poor nor good	Good	Very good
Your perceived overall comfort during the exposure?	1	2	3	4	5
Comments related to overall comfort? ______________________________					
	No effect	**Little effect**	**Moderate effect**	**Big effect**	**Very big effect**
If heated, the effectiveness of the heating system?	1	2	3	4	5
The effect of the exposure on your physical performance?	1	2	3	4	5
The effect of the exposure on your mental performance?	1	2	3	4	5
Comments related to overall performance? ______________________________					

Please write any additional comments concerning the exposure.

____

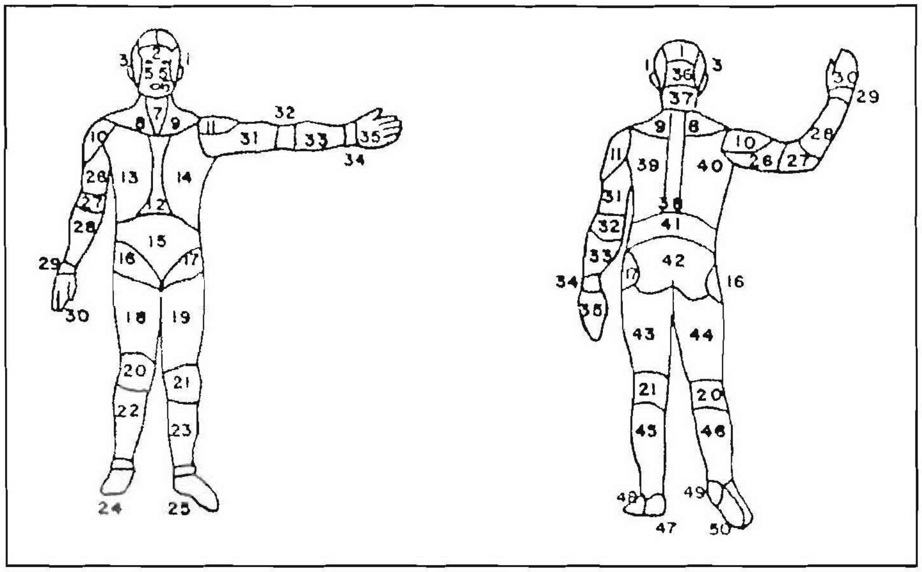
____

Using the numbers in item 1 below, indicate the locations of any discomfort you felt during the dive.

Using the appropriate numbers and letters provided in items 1 and 3, indicate the intensity and type of discomfort. To illustrate, a severe sharp pain in the left foot would be recorded as follows:

Location	Intensity	Type	Description
25	5	C	

1.



2.

Intensity

1	2	3	4	5
Mild		Moderate		Severe

3.

A. Throbbing
B. Burning
C. Sharp
D. Dull
E. Stiffness
F. Searing
G. Grinding
O. Other (specify)

Location	Intensity	Type	Description